DEPARTMENT OF DEFENSE

MILITARILY CRITICAL TECHNOLOGIES LIST

SECTION 14: MATERIALS AND PROCESSING TECHNOLOGY

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PREFACE

A. THE MILITARILY CRITICAL TECHNOLOGIES PROGRAM (MCTP)

The MCTP supports the development and promulgation of the congressionally mandated Militarily Critical Technologies List (MCTL) and the Developing Science and Technologies List (DSTL).

Congress assigns the Secretary of Defense the responsibility of providing a list of militarily critical technologies (the MCTL) and of updating this list on an ongoing basis. The MCTL identifies technologies crucial to weapons development and has been a key element in evaluating U.S. and worldwide technological capabilities. The MCTP has provided the support for a wide range of assessments and judgments, along with technical justifications for devising U.S. and multilateral controls on exports. The DSTL, another MCTP product, identifies technologies that may enhance future military capabilities and provides an assessment of worldwide science and technology (S&T) capabilities.

The MCTP process is a continuous analytical and information-gathering process that refines information and updates existing documents to provide thorough and complete technical information. It covers the worldwide technology spectrum and provides a systematic, ongoing assessment and analysis of technologies and assigns values and parameters to these technologies.

Technical Working Groups (TWGs), which are part of this process, provide a reservoir of technical experts who can assist in time-sensitive and quick-response tasks. TWG chairpersons continuously screen technologies and nominate items to be added or removed from the list of militarily critical technologies. In general, TWG members are drawn from about 1,000 subject matter experts (SMEs) from the military Services, DoD and other federal agencies, industry, and academia. A balance is maintained between public officials and private-sector representatives. TWGs collect a core of intellectual knowledge and reference information on an array of technologies, and these data are used as a resource for projects and other assignments. Working within an informal structure, TWG members strive to produce precise and objective analyses across dissimilar and often disparate areas. Currently, the TWGs are organized to address 20 technology areas:

Aeronautics
Armament and Energetic Materials
Biological
Biomedical
Chemical
Directed and Kinetic Energy Systems
Electronics
Energy Systems
Ground Combat Systems
Information Security
Information Systems
Lasers, Optics, and Imaging
Processing and Manufacturing
Marine Systems
Materials and Processes
Nuclear Systems
Positioning, Navigation, and Time
Signature Control
Space Systems
Weapons Systems

B. THE MILITARILY CRITICAL TECHNOLOGIES LIST (MCTL)

The expanded MCTL provides a coordinated description of existing goods and technologies that DoD assesses would permit significant advances in the development, production, and use of military capabilities by potential adversaries. It includes goods and technologies that enable the development, production, and employment of weapons of mass destruction (WMD) and their means of delivery. It includes discreet parameters for systems; equipment;

subassemblies; components; and critical materials; unique test, inspection, and production equipment; unique software, development, production, and use know-how.

C. LEGAL BASIS FOR THE LIST OF MILITARILY CRITICAL TECHNOLOGIES

The Export Administration Act (EAA) of 1979 assigned responsibilities for export controls to protect technologies and weapons systems. It established the requirement for DoD to compile a list of militarily critical technologies. The EAA and its provisions, as amended, were extended by Executive Order and Presidential directives.

D. USES AND APPLICATIONS

The MCTL is not an export control list. Items in the MCTL may not appear on an export control list, and items on an export control list may not appear in the MCTL. The document is to be used as a reference for evaluating potential technology transfers and for reviewing technical reports and scientific papers for public release. Technical judgment must be used when applying the information. It should be used to determine if the proposed transaction would result in a transfer that would give potential adversaries access to technologies whose specific performance levels are at or above the characteristics identified as militarily critical. It should be used with other information to determine whether a transfer should be approved.

This document, MCTL Section 14: Materials and Processing Technology supersedes MCTL Part I, Sections 11.1, 11.3, 11.5 and 11.6.

INTRODUCTION

A. *ORGANIZATION OF THE MILITARILY CRITICAL TECHNOLOGIES LIST (MCTL)*

The MCTL is a documented snapshot in time of the ongoing MCTP militarily critical technology process. It includes text and graphic displays of technical data on individual technology data sheets.

Each section contains subsections devoted to specific technology areas. The section front matter contains the following:

- *Scope* identifies the technology groups covered in the section. Each group is covered in a separate subsection.
- *Highlights* identify the key facts in the section.
- *Overview* discusses the technology groups identified under "Scope."
- *Background* provides additional information.

Each technology group identified under Scope has a subsection that contains the following:

- *Highlights* identify the key facts found in the subsection.
- *Overview* identifies and discusses technologies listed in data sheets that follow.
- *Background* provides additional information.
- *Data Sheets,* which are the heart of the MCTL, present data on individual militarily critical technologies. The principal data element is the Critical Technology Parameter, which is the technology parameter that defines where the technology would permit significant advances in the development, production and use of military capabilities of potential adversaries.

B. *WORLDWIDE TECHNOLOGY CAPABILITY*

The technology data sheets are of primary interest to all users. They contain the detailed parametric information that managers, R&D personnel, program managers (PMs), and operators need to execute their responsibilities.

- *Critical Technology Parameter(s)* includes the parameter, data argument, value, and level of the technology where its technical performance would permit significant advances in the development, production, and use of the military capabilities of potential adversaries.
- *Critical Materials* are those materials that are unique or enable the capability or function of the technology.
- *Unique Test, Production and Inspection Equipment* includes that type of equipment that is critical or unique.
- *Unique Software* is software needed to produce, operate, or maintain this technology that is unique.
- *Major Commercial Applications* addresses commercial uses of this technology.
- *Affordability Issues* are those factors that make this technology an affordability issue.
- *Export Control References* indicate international and U.S. control lists where this technology is controlled. It does not mean that the technology is controlled at the parameter level on the data sheet.

  Note: Export control references are:

WA ML 2	(Wassenaar Arrangement Munitions List Item)
WA Cat 1C	(Wassenaar Dual Use List Subcategory)

MTCR 17	(Missile Technology Control Regime Item)
NTL B3	(Nuclear Trigger List Subitem – Nuclear Suppliers Group)
NDUL 1	(Nuclear Dual Use List Item – Nuclear Suppliers Group)
AG List	(Australia Group List)
BWC	(Biological Weapons Convention)
CWC	(Chemical Weapons Convention)
USML XII	(United States Munitions List Category – ITAR)
CCL Cat 2B	(Commerce Control List Subcategory – EAR)
NRC A	(Nuclear Regulatory Commission Item)

SECTION 14—MATERIALS AND PROCESSING TECHNOLOGY

Scope

Highlights

- Advanced propulsion and power systems require advanced materials for high-thrust/weight ratios and improvements in the efficiency of power systems. Those attributes are critical for long-duration, highly stressed military missions.
- Advanced magnetic nanocrystalline alloys and nonstructural composites; high-strength, low-loss magnetic materials; and superconducting composite conductors are required for future propulsion and power systems.
- Armor materials for ballistic protection of weapon systems and the individual warfighter rely more and more on analytically derived arrays of fully dense, hard ceramics in combination with composite laminates and metallic layers. Ceramics of interest are aluminum oxide, silicon carbide, titanium diboride, boron carbide, and combinations.
- Key structural materials for load-bearing applications in military platforms are metals, polymers, ceramic, and composites. High-strength and stiffness, coupled with light weight, are crucial for many weapons systems; hence, the importance of composites.
- High-temperature, high-strength materials are important in propulsion systems, for thermal protection of reentry bodies, in leading edges, in missile motor case insulation and exit cones, and in coatings of gas turbines.
- Other important classes of materials are discussed in different MCTL Sections: Electronic materials in Section 8, Electronics Technology; optical materials in Section 11, Lasers, Optics and Imaging Technology; materials for electrochemical power sources (batteries, fuel cells) in Section 7, Energy Systems Technology; nuclear materials in Section 15, Nuclear Systems Technology; some aspects of magnetic and dielectric materials in Section 18, Signature Control Technology.

OVERVIEW

This section covers the materials and processing technology areas that are addressed by the Department of Defense (DoD) Reliance Panels—propulsion and power materials; structural materials (high-strength and high-temperature, anti-armor); materials for survivability; materials for reliability, maintainability, and sustainability; sensor and electronic materials; and materials for the individual warfighter. All six areas are explained in the following text. Data sheets are included for three areas (see *Scope*) that have militarily critical technologies.

Many classes of materials inherently have both military and commercial applications. Although commercial applications are generally at lower performance levels than those of the military, this is not always the case. This section identifies those materials that provide specific military advantage and covers the physical properties, technical properties, and processing required to achieve that advantage. The technologies include materials engineered to defeat an enemy threat and functional materials needed to preserve the capability of high-performance hardware in daily operations. This section addresses six categories of relevant materials technology. As noted in the Scope, this report updates the first three categories on this list.

Propulsion and Power Materials includes the development of materials and processes; mechanical behavior/life-prediction methodologies; and affordable fabrication and manufacturing capabilities for DoD propulsion systems, including electromagnetic propulsion, power systems, motors, generators, power conditioning, and control. Specific examples are (1) structural materials for turbine engines, hypersonic engines, and rocket engines and (2) superconducting and magnetic materials for electrical energy generation, storage control and conversion devices, and railguns. High-temperature structural materials are covered in Section 14.2, Structural Materials (High-Strength and High-Temperature, Anti-Armor). Materials for electrochemical power sources (batteries and fuel cells) are discussed in Section 7, Energy Systems Technology.

Structural Materials (High-Strength and High-Temperature, Anti-Armor) are basically metals, ceramics, polymers, carbon, and their composites for load-bearing or mechanical support and thermal-management applications for weapon system platforms and, in the case of anti-armor, materials for kinetic-energy penetrators and shaped-charge liners. Platform structural materials for aircraft, ships, missiles, and space and ground vehicles are designed to enhance affordability and improve system performance in terms of stealth, payload, and range. Weight reduction by compositing is a key design element.

Materials for Survivability, are as numerous and varied as the threats they are meant to negate. Most simply, their critical primary functions are to protect from, to confuse, and to avoid threats. One consequence is that parasitic weight is added to the system being protected. In this regard, a common aim of material development for all the disparate materials in this technical area is to limit weight, drag, and other physical properties that could sacrifice system performance, largely through novel processing, novel compositing, or the introduction of multifunctionality. A second commonality among these technologies is the development of computational models that describe the life of materials from their synthesis and processing to simulations and predictions of responses, to deliberate and environmental threats. Materials for chemical and biological defense are still in the research and development stage, and thus are not discussed here. Materials for laser protection are covered in another MCTL section, Section 11, Lasers, Optics and Imaging Technology. The data sheets for this section are thus only for advanced armor materials.

Materials for Reliability, Maintainability, and Sustainability provide essential materials and processing technology advances to increase the service life and reduce the sustainment costs of DoD platforms, systems, and components without compromising their warfighting capabilities. Efforts include a mix of life extension, increased reliability, and innovative affordable sustainment approaches that provide multifunctional capabilities. Life extension is addressed through corrosion control and coating technologies; lubricants, fluids, and wear-resistant coatings; elastomers; condition-based maintenance and repair; and nondestructive evaluation. These efforts are essential to the sustained reliability, maintainability, operational readiness, and performance of military systems and equipment and to ensure compliance with current and emerging environmental regulations. Coatings, lubricants, and fluids are no longer listed in the MCTL. Elastomers and seals are used by many countries, and the technology is public knowledge. NDE hardware design and use is a multinational endeavor. Thus, there are no specific data sheets for this section.

Sensor and Electronic Materials incorporates the growth and characterization of a variety of materials whose predominant attributes are their electronic, magnetic, or optical properties, along with the materials-processing technology necessary to make the materials technically and economically viable for use in DoD systems. Specific examples are wide-bandgap semiconductors; materials for optical sensors, sources, and control; magnetic, ferroelectric, piezoelectric, and superconductive materials; electromagnetic transparencies; and nano and biomolecular materials. Electronic and optical materials are not discussed in this section because they are covered in other MCTL sections, specifically Section 8, Electronics Technology, and Section 11, Lasers, Optics and Imaging Technology, respectively. Superconducting and magnetic materials for motors, generators, and power conditioning and control are covered in Section 14.1, Propulsion and Power Materials, below.

Materials for the Individual Warfighter. The transformation of the military is placing an increasing burden on the capabilities and survivability of the individual warfighter. Advanced materials play a critical role in ensuring the success by addressing critical needs for the individual warfighter by (1) providing protection against the surrounding climatic elements and contaminated air and water; (2) ensuring necessary sustaining elements, such as electrical power and potable water; and (3) augmenting human performance, such as provided by an exoskeleton. Because materials in this section are in the early research and development stages, they are not included in this MCTL.

BACKGROUND

The six categories are consistent with the taxonomy developed by the DoD Reliance Group for the Materials and Processing Joint Program Plan. The Group consists of specialists in materials and processing from the military departments and defense agencies. The technologies discussed include those devoted to improving, upgrading, and sustaining the existing military equipment and “transformation” advances that will enable new military capabilities such as information warfare; uninhabited air, ground, and sea-going vehicles; long-range, high-speed precision armaments; and space vehicles.

SECTION 14.1—PROPULSION AND POWER MATERIALS

Highlights

- Developing materials for propulsion and power will be one of the most challenging and important areas of future materials research and manufacturing.
- The need to "project power" globally and rapidly requires lightweight materials to increase maneuverability and to reduce power requirements.
- Materials that improve the efficiency of power systems are critical for long-duration missions.
- Developing new energy technologies that will permit exploitation of new energy sources is vital to supporting warfighters.

OVERVIEW

Propulsion and power materials includes the development of materials and processes; mechanical behavior/life-prediction methodologies; and affordable fabrication and manufacturing capabilities for DoD propulsion systems, including electrochemical power sources, electromagnetic propulsion, ram and scramjets, power systems, motors, generators, power conditioning, and control. Specific examples are (1) structural materials for turbine engines, hypersonic engines, and rocket engines and (2) superconducting and magnetic materials for electrical energy generation, storage control and conversion devices, and railguns. High-temperature structural materials such as metals, ceramics, composites, and insulating materials are covered in Section 14.2, Structural Materials (High-strength and High-Temperature, Anti-Armor). Electrochemical power sources (batteries, fuel cells) are covered in Section 7, Energy Systems Technology.

BACKGROUND

Magnetic materials are used for inductors in both high-frequency (ferrites) and low-frequency (magnetic ribbons) applications. New nanosynthesis techniques are able to produce nanocrystalline composites that will greatly improve the power-handling capability of high- and low-frequency inductors. Superconducting composite conductors are developed for Navy and Air Force weapons systems. Other military applications include magnets for energy storage, aerospace generators, electromagnetic launch, directed-energy weapons, and decoy applications.

LIST OF MCTL TECHNOLOGY DATA SHEETS
14.1. PROPULSION AND POWER MATERIALS

MCTL DATA SHEET 14.1-1. MAGNETIC NANOCRYSTALLINE ALLOYS AND COMPOSITES

Critical Technology Parameter(s)	Ferrites: a. Saturation inductions above 1T at frequencies greater than 10 MHz. b. Initial relative permeability above 1,000 for a flux density of 0.1 mT and an operational frequency of 10 MHz. Nanocrystalline Composites: a. Saturation induction above 1.9T at frequencies greater than 100 kHz. b. Core loss below 10 W/kg for a flux density of 100 mT and an operational frequency of 100 kHz.
Critical Materials	Ceramic ferrites (iron, nickel, manganese oxides). Magnetic ribbons (iron, nickel, manganese nano-structured alloys).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	High-frequency inductors for radar and low-frequency inductors for power electronics.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Magnetic materials are used for inductors in both high-frequency (ferrites) and low-frequency (magnetic ribbons) applications. However, low saturation fields limit the ferrites and high core losses limit the magnetic ribbons. New nanosynthesis techniques are able to combine the best of both features into a nanocrystalline composite that will greatly improve the power-handling capability of high- and low-frequency inductors.

MCTL DATA SHEET 14.1-2. HIGH-STRENGTH, LOW-LOSS MAGNETIC MATERIALS FOR POWER GENERATORS

Critical Technology Parameter(s)	a. Saturation inductions greater than 2T. b. Yield strength greater than 700 MPa. (101 psi) c. 400 Hz, 2 T core losses less than 50 W/kg. d. Structural stability for prolonged use at temperatures in excess of 500 °C. e. Form suitable for fabrication into rotors using conventional stacked laminations.
Critical Materials	Iron-cobalt soft magnetic alloys.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Aircraft generators, auxiliary power sources for home and business, magnetic bearings for large machinery.
Affordability Issues	Not an issue.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

The demand for higher electrical output in aerospace generators has pushed conventional alloy development to its limit. Higher output requires higher rotational speeds, which increase the mechanical strength requirements of the generator rotors. For soft magnetic materials, this usually involves refining the crystallite or grain size, taking advantage of the Hall-Petch effect (yield strength is inversely proportional to the square root of the grain size). Commercial materials with grain sizes approaching 1 micrometer are available. However, the core losses are also dependent on the grain size. The hysteretic component of core loss increases inversely with the grain size. This leads to a situation where small increases in mechanical strength are accompanied by disproportionately larger increases in core loss in the form of heat. The situation has been reached where heat removal from the generator has become a serious issue requiring ever-larger heat exchangers, compromising overall aircraft performance.

One possible solution is to delink the magnetic and mechanical behavior by use of composite materials. A composite of a soft magnetic alloy with a mechanical strengthening phase would appear to be the desirable solution, particularly if the resulting composite could be fabricated into rotor laminations with conventional fabrication techniques.

MCTL DATA SHEET 14.1-3. SUPERCONDUCTING COMPOSITE CONDUCTORS

Critical Technology Parameter(s)	YBCO conductors: Total length greater than 1,000 meters in piece lengths greater than 100 meters. Engineering critical current density of the conductor exceeds 20,000 A/cm^2 at 65 K in magnetic fields less than 2T over a minimum of 10 m.
Critical Materials	Yittrium, bismuth, barium, strontium, calcium, copper, nickel, silver.
Unique Test, Production, Inspection Equipment	Cryogenic refrigerators cooling to 30 K less than T less than 100 K.
Unique Software	None identified.
Major Commercial Applications	Motors, generators, transmission lines, transformers, fault current limiters, energy storage.
Affordability Issues	Less than $20/K amp-meter.
Export Control Reference	WA Cat 1, CCL Cat 1.

BACKGROUND

Superconducting composite conductors are under active development for military systems (e.g., propulsion motors for naval ships, generators for naval ships and for naval and Air Force weapons systems). Other military applications may include magnets for energy storage, for electromagnetic launch or directed-energy weapons, or for decoy applications.

SECTION 14.2—STRUCTURAL MATERIALS (HIGH-STRENGTH AND HIGH-TEMPERATURE, ANTI-ARMOR)

Highlights

- Key structural materials for load-bearing applications in military platforms are metals, ceramics, polymers, and composites.
- High-strength and stiffness, coupled with light weight, are crucial for many weapon systems; hence, the importance of composites.
- High-temperature, high-strength materials are important in propulsion systems, thermal protection for re-entry bodies, leading edges, missile motor case insulation and exit cones, and coatings in gas turbines.
- Processing and manufacturing of materials and components aim at producing structures with increased performance, durability and survivability.
- Key metals for kinetic-energy penetrators and shaped-charged liners are tungsten, depleted uranium, copper, and tantalum.

OVERVIEW

Structural materials technology includes development, synthesis, processing, and characterization of a wide class of monolithic alloy and composite materials, as well as specialized coatings. Because the structural materials category is so broad, it has been subdivided into (1) high-strength materials used for fabrication of platforms, vehicles, and weapons; (2) high-temperature materials used primarily for propulsion; and (3) anti-armor materials. Armor materials are discussed in Section 14.3, Materials for Survivability.

BACKGROUND

High-strength materials include ferrous and nonferrous metal alloys and metal and polymer matrix composites. Included are maraging ultrahigh-strength and high-strength low-alloy steels; high-strength aluminum and titanium alloys; aluminum-lithium alloys; and aluminum- and polymer-matrix composites, including matrix and reinforcement constituents. Anti-armor materials include depleted uranium, tungsten, copper, and tantalum. Materials suitable for use at high temperatures include nickel- and cobalt-based super-alloys and advanced intermetallics; tungsten and molybdenum alloys; oxide, carbide, nitride, and boride ceramics (in monolithic and composite forms); carbon-carbon and SiC-carbon composites; "high-temperature" aluminum alloys; and high-temperature protective thermal barrier coatings. Advances in all these areas are occurring steadily. As an example, major recent advances in thermal barrier coatings have resulted in increased insertion of new coatings on jet engine components for corrosion and erosion protection.

LIST OF MCTL TECHNOLOGY DATA SHEETS
14.2. STRUCTURAL MATERIALS (HIGH-STRENGTH AND HIGH-TEMPERATURE, ANTI-ARMOR)

MCTL DATA SHEET 14.2-1. POWDER METALLURGY ALUMINUM ALLOYS

Critical Technology Parameter(s)	Aluminum alloys with a tensile strength of (1) 240 MPa (34.5 ksi) or more at 473 K (200 °C) *or* (2) 415 MPa (60 ksi) or more at 298 K (25 °C). Made from metal alloy powder, flakes, ribbons, thin rods, or particulate material.
Critical Materials	Aluminum alloys (Al-Mg-X or Al-X-Mg, Al-Zn-X or Al-X-Zn, Al-Fe-X or Al-X-Fe); where “X” equals 1 or more alloying elements.
Unique Test, Production, Inspection Equipment	Equipment for vacuum atomization, gas atomization, rotary atomization, splat quenching, melt spinning and comminution, melt extraction and comminution, mechanical alloying, and hot isostatic pressing.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Powder metallurgy is a major manufacturing method for producing shapes and components of aluminum alloys for military and civilian use. Some aspects of microstructure and composition can be achieved that cannot be produced in cast and wrought materials. This, in turn, develops superior properties, for example, creep strength.

MCTL DATA SHEET 14.2-2. ALUMINUM LITHIUM ALLOYS

Critical Technology Parameter(s)	Aluminum-lithium alloys with a yield strength of 500 MPa (72.5 ksi) and an elongation of 10%, a density 5% less than alloy 2024, and a spectrum fatigue behavior three times better than 2024.
Critical Materials	Aluminum-lithium alloys (Al-Mg-Li, Al-Li-Cu-X).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Super-lightweight fuel tank for weight saving on space shuttle; fatigue-critical bulkheads and other parts.
Affordability Issues	Higher cost than conventional aluminum alloys.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Aluminum-lithium alloys are attractive for aerospace application because they have lower density and higher modulus than conventional aluminum aerospace alloys. Each weight percent of lithium lowers the density of aluminum by approximately 3 percent and increases the elastic modulus by approximately 6 percent.

MCTL DATA SHEET 14.2-3. ALUMINUM AND ALUMINUM ALLOY MATRIX COMPOSITES

Critical Technology Parameter(s)	Stiffness greater than 103 GPa (15 Msi) and fracture toughness greater than 20 MPa √m (18 ksi √in.); increased uniformity and reliability and reduced cost.
Critical Materials	Reinforcement particles, fibers, and whiskers; protective fiber/whisker coatings.
Unique Test, Production, Inspection Equipment	For powder-processed composites, same limitations as for powder metallurgy aluminum alloys apply (see Data Sheet 14.2-1).
Unique Software	Process-control software.
Major Commercial Applications	Sporting goods, power transmission lines, automotive engine blocks (3M Corp. Al/Al_2O_3).
Affordability Issues	Affordability will depend on the application, material, composition, manufacturing process, and the material being displaced.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

The design of many aerospace components is stiffness critical and monolithic aluminum with a Young's modulus of 76 GPa (11 Msi) is a relatively low stiffness metal. The additional stiffness (and strength) obtained by compositing allows lighter weight designs and a concomitant increase in operating temperature.

MCTL DATA SHEET 14.2-4. ULTRAHIGH-STRENGTH/HIGH-TOUGHNESS STEEL

Critical Technology Parameter(s)	Yield strength greater than 1.965 GPa (285 ksi), toughness greater than 111 MPa √m. (100 ksi √in.).
Critical Materials	"AerMet 100" patented by Carpenter Technology Co.
Unique Test, Production, Inspection Equipment	None identified; composition is patented by Carpenter Technology Co.
Unique Software	None identified.
Major Commercial Applications	Commercial aircraft, landing gear, and tooling.
Affordability Issues	Reduced inspection and maintenance requirements. Material cost for high-toughness steels is much greater than ultrahigh-strength steels such as 300M.
Export Control References	WA Cat 1, CCL Cat 1, MTCR Cat 2, Item 6.

BACKGROUND

There has been considerable improvement in high-strength, high-toughness, corrosion-resistant steels for landing gear applications.

MCTL DATA SHEET 14.2-5. NICKEL-BASED ALLOYS

Critical Technology Parameter(s)	Nickel alloys with: (1) Ultimate tensile strength greater than 1,035 MPa (150 ksi) at 815 °C. (2) Creep rupture Larsen-Miller parameter, P = T(C + log t), greater than 29, where C = 20, T = temperature (K), and t = rupture life (seconds) at 345 MPa (50 ksi).
Critical Materials	Nickel alloys (Ni-Al-X, Ni-X-Al) qualified for turbine engine parts or components, that is, with fewer than 3 nonmetallic particles (introduced during the manufacturing process) larger than 100 μm in 10^9 alloy particles where "X" equals 1 or more alloying elements.
Unique Test, Production, Inspection Equipment	Made in controlled environment by any of the following processes: vacuum atomization, inert gas atomization, melt spinning, melt extraction and comminution; or mechanical alloying. Isostatic press, extrusion, isothermal press forge.
Unique Software	Process modeling for material efficiency, structural property control, quench crack prevention, and residual stresses.
Major Commercial Applications	GE-90, CFE 738, and CF6-80 HPT and HPC disks and seals.
Affordability Issues	Process yield can be improved through screening and consolidation, thereby lowering cost.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

High-purity, powder-processed nickel-based superalloys are used in critical rotating components for aeropropulsion systems, marine gas turbines, and some auxiliary power units.

MCTL DATA SHEET 14.2-6. THERMAL BARRIER COATINGS

Critical Technology Parameter(s)	Temperature at metal-coating interface greater than 1,150 °C (2,100 °F).
Critical Materials	Specific formulations tend to be proprietary but typically contain multilayers of alumina- and yttria-stabilized zirconia. Molybdenum disilicide is also utilized for oxidation protection of very high-temperature structures.
Unique Test, Production, Inspection Equipment	Plasma spray, chemical vapor deposition, e-beam deposition, laser ablation processing capabilities.
Unique Software	None identified.
Major Commercial Applications	Coatings for boilers, reactors and furnaces, and coated components for commercial jet engines and marine and land-based turbines.
Affordability Issues	Increase turbine blade life and thereby reduce maintenance costs.
Export Control References	WA Cat 2, CCL Cat 2.

BACKGROUND

Thermal protection is required to protect airfoils from corrosion or erosion in the extremely hot gas path temperatures in modern, high-performance aeroengines.

MCTL DATA SHEET 14.2-7. BURN–RESISTANT TITANIUM ALLOYS

Critical Technology Parameter(s)	An alloy for gas turbine engine compression system applications that supports sustained operating temperatures 220 °C (400 °F) higher than that of traditional structural titanium alloys. Alternatively, any titanium alloy that allows a higher auto-ignition temperature than Ti-6Al-4V.
Critical Materials	Pratt & Whitney alloy C—a proprietary composition.
Unique Test, Production, Inspection Equipment	Procedures and equipment designed for contamination-free processing of alloys and powders or for superplastic forming and diffusion bonding.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1, NSG Cat 2.

BACKGROUND

Traditional structural titanium alloys will readily burn in the presence of high-pressure air and a source of ignition, particularly when used in the compressor section of gas turbine engines, strategic launch vehicles, and tactical missiles.

MCTL DATA SHEET 14.2-8. TITANIUM-MATRIX COMPOSITES

Critical Technology Parameter(s)	Tensile strength greater than or equal to 1,100 MPa (160 ksi), elastic modulus greater than or equal to 172 GPA (25 Msi), and density less than or equal to 4.4×10^3 kg/m^3 (0.16 lb/in.^{3}); improved strength, toughness, temperature capability, and reliability.
Critical Materials	Silicon carbide monofilament reinforcement fibers and titanium alloy foil.
Unique Test, Production, Inspection Equipment	Fiber coating apparatus and hot isostatic pressing and canning equipment.
Unique Software	Process-control software, consolidation models, and fiber spacing procedures.
Major Commercial Applications	None identified.
Affordability Issues	Very expensive at present.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

In an effort to reduce the weight of aircraft propulsion components and even some aircraft structures, titanium matrix composites have been developed to provide high-strength and stiffness.

MCTL DATA SHEET 14.2-9. TITANIUM ALUMINIDES

Critical Technology Parameter(s)	Ductility greater than 0.5% elongation at 25 °C and tensile strength greater than 650 MPa (94 ksi) at 815 °C.
Critical Materials	Containing more than 10 weight percent aluminum and at least one additional alloying element.
Unique Test, Production, Inspection Equipment	Vacuum, gas or rotary atomization, splat quenching, melt spinning and comminution, mechanical alloying or plasma spray, cospray or osprey process, and isostatic pressing.
Unique Software	None identified.
Major Commercial Applications	Automobile engine components. Aircraft engines and diesel engine turbochargers.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1, NSG Cat 2.

BACKGROUND

Titanium aluminide intermetallic compounds offer a lighter weight, high-temperature alternative to conventional nickel based superalloys for use in aircraft engines, marine gas turbines, stationary power plants, and auxiliary power units.

MCTL DATA SHEET 14.2-10. METAL ALLOY AND INTERMETALLIC ALLOY POWDER PRODUCTION, HANDLING, AND CONSOLIDATION

Critical Technology Parameter(s)	Metals, alloys, and particulates in the form of powder, uncomminuted flakes, ribbons, or thick rods with contamination levels less than 3 unwanted foreign particles larger than 100 μm per billion metal particles; improved cleanliness and reduced cost; uniform particle size, shape, and composition.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Controlled environment equipment required for contamination-free powder. Vacuum atomization, gas atomization, rotary atomization, splat quenching, melt spinning and comminuting, melt extraction and comminuting, or mechanical alloying in metal and alloy powder for particulate materials. Handling, consolidation, and sintering equipment designed for contamination-free products and for consolidation and isostatic presses.
Unique Software	Process-control software and know-how.
Major Commercial Applications	Automotive, optical, business machines, electron tubes, catalysts, and gas turbine engines.
Affordability Issues	Certain products made of refractory metals such as tungsten and molybdenum with high melting temperatures are often manufactured by powder metallurgy. Products which may be more advantageously produced by powder metallurgy include those in which purity, exact compositions, or a high degree of homogeneity is essential. Powder metallurgy alloys lend themselves to rapid prototyping.
Export Control References	WA Cat 1, CCL Cat 1, MTCR Cat 2, Item 4.

BACKGROUND

Powder metallurgically prepared and processed alloys can provide a significant performance, and in some cases economic, advantage over ingot-derived product. Examples of powder metallurgy products that cannot be manufactured by other means include metals with high melting points for lamp filament, nonconsumable welding electrodes, electronic vacuum tube components, and heavy alloys for high-mass and radiation shielding.

MCTL DATA SHEET 14.2-11. FIBROUS OR FILAMENTARY POLYMERIC MATERIALS

Critical Technology Parameter(s)	Organic fibers or filaments with tensile strength greater than 3.4 GPa (493 ksi) and tensile modulus greater than 160 GPa (23 msi), and for use above 170 °C.
Critical Materials	Poly-paraphenyelne terephthalamide used to fabricate Dupont Kelvar 149, and polyp-phenylene-2,6-benzobisoxazole used to fabricate Toyobo Zylon family of fibers.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Sporting equipment, transportation systems requiring reduced weight, protective clothing for police and firefighters, high-performance marine hulls.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Strong polymer fibers provide reinforcing filaments that increase the strength and stiffness of polymer matrix composites.

MCTL DATA SHEET 14.2-12. QUARTZ AND LEACHED GLASS FIBERS

Critical Technology Parameter(s)	Fibers with specific modulus greater than 24.9 MPa/kg/m^3 and a melting or decomposition point greater than 1,600 °C (2,912 °F).
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Equipment for wet spinning of refractory ceramics, leaching and washing equipment for surface finish controls, and furnaces to preprocess material at temperatures greater than 954 °C (1,750 °F).
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

These fibers are used in structural composites for heat shields, reentry vehicles, decoys, and rocket motor exit cones, all of which are subjected to extremely high temperatures. Because of their electrical properties, they are also used for high-temperature radomes and antenna windows.

MCTL DATA SHEET 14.2-13. CONTINUOUS CARBON FIBROUS OR FILAMENTARY MATERIALS

Critical Technology Parameter(s)	Continuous carbon fibers or filaments with a specific tensile strength greater than 23.5 $\times 10^4$ GPa/g/cm^3 and a specific tensile modulus greater than 12.7 $\times 10^6$ GPa/g/cm^3. Properties should be determined using Suppliers of Advanced Composite Materials Association (SACMA) recommended methods SRM 12-17.
Critical Materials	Hexcel IM6 and IM7; Toray T800 and M40J; Toho G40-800.
Unique Test, Production, Inspection Equipment	Furnaces capable of exceeding 1,200 °C in a controlled atmosphere.
Unique Software	None identified.
Major Commercial Applications	Sporting equipment, aircraft parts, transportation systems requiring reduced weight, high-performance marine hulls, infrastructure (bridges/buildings), space launch vehicles, brakes.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

This data sheet addresses carbon fibers that are used to provide both strength and stiffness primarily for aerospace structural applications.

Carbon fibers may be classified according to the precursor materials from which they are manufactured. *Three principal organic precursor materials are used to produce carbon fibers:* polyacrylonitrile, pitch, and rayon.

Each of these precursor materials is converted into carbon fibers by a high-temperature carbonization/graphitization process.

The precursor-to-carbon-fiber conversion process follows this sequence of steps:

- *Stabilization*—Carried out at temperatures less than 400 °C (less than 750 °F) in various atmospheres. The fibers are often stressed during this stage of the process to improve the orientation of the molecular structure and increase carbon fiber strength and modulus (stiffness).
- *Carbonization*—Accomplished at temperatures from 800–1200 °C (1470–2190 °F). The stabilized fibers are pyrolyzed in inert environments to reduce their impurity levels and increase their crystallinity. Fibers may be shrunk or stretched in this step. As in the stabilization step, any increase in the preferred orientation generally increases tensile modulus. Carbonization produces fibers with a carbon content between 93 percent and 95 percent.
- *Graphitization*—An additional pryolysis step at temperatures in excess of 2,000 °C (3,630 °F) in inert environments. Graphitization produces fibers having a carbon content that exceeds 99 percent.
- *Surface treatment*—Applied to the carbonized/graphitized fibers to optimize the interaction between the carbon fibers and the matrix material for composite fabrication.
- *Sizings, coatings and finishes*—Applied to fiber bundles (tows) to improve their handing characteristics.

Carbon fibers are typically characterized according to their physical and mechanical properties, which determine their application, or by the number of fibers included in a bundle (tow size), twist, and sizing.

Fibers made from carbon nanotubes, both single wall and multiwall are currently receiving much attention because of their potential for being incorporated into polymer matrix composites for strengthening and stiffening.

MCTL DATA SHEET 14.2-14. POLYMERIC RESIN MATRIX MATERIALS FOR COMPOSITE STRUCTURES AND LAMINATES

Critical Technology Parameter(s)	The ability to perform at temperatures greater than or equal to 145 °C (293 °F) in operation. This ability is measured by the glass transition temperature (Tg) of the resin as determined by ASTM 4065.
Critical Materials	Aromatic polyimides, bismaleimides, PMR-15, AFR700B, AFR-PE-4, PETI-5, PETI-330.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	High-temperature seals, commercial aircraft engine ducts.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

This data sheet addresses polymeric resins utilized as the matrix for glass and carbon-fiber-reinforced composites. It is intended to primarily address resins for composites that perform at temperatures above 145 °C and that are principally used for aerospace applications. It does not address polyester, vinyl ester, or most epoxy resins used for run-of-the-mill commercial products.

Composite materials continue to gain acceptance based on weight reduction, reduced assembly labor, and tailorable electrical and mechanical properties. As a result, composite materials are increasingly used in aerospace and terrestrial applications where they are expected to perform at elevated temperatures.

MCTL DATA SHEET 14.2-15. RESIN IMPREGNATED FIBER PREPREGS BASED ON FIBROUS OR FILAMENTARY REINFORCEMENTS

Critical Technology Parameter(s)	Two types of prepreg are of interest: (1) Any prepreg that contains a fiber identified in Data Sheet 14.2-13 (specific modulus greater than 12.7×10^6 GPa/g/cm^3 and specific strength greater than 23.5×10^4 GPa/g/cm^3) regardless of the Tg of the resin. (2) Any prepreg that when cured is capable of having a glass transition temperature (Tg) greater than 145 °C (as defined by ASTM 4065) regardless of the fiber it contains.
Critical Materials	Any fiber with mechanical properties above those listed in Data Sheet 14.2-13 and any matrix resin that is capable of producing a glass transition temperature (Tg) greater than 145 °C after cure.
Unique Test, Production, Inspection Equipment	Fiber treatment, fiber coating and prepregging equipment (mixers, coaters, vertical or horizontal ovens, and rewind equipment).
Unique Software	None identified.
Major Commercial Applications	Sporting equipment, aircraft parts, transportation systems requiring reduced weight, high-performance marine hulls, infrastructure (bridge/buildings), and space launch vehicles.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1, USML Cat XXI.

BACKGROUND

Prepreg is defined as ready-to-mold material in sheet form or ready-to-wind material in roving form that has already been impregnated with a thermoset or thermoplastic matrix resin and has been stored ready for use. Thermoset resin prepregs are supplied to the fabricator where the final component is laid up and the cure to finish the composite is completed through the application of heat, vacuum, and pressure. Advantages offered through the use of prepreg materials include precisely controlled fiber/resin ratios, highly controlled and repeatable drape characteristics, improved control of fiber-placement angles, and controlled resin flow during final cure. These attributes contribute to reliably fabricating high-quality composite components and structures for rocket systems, unmanned air vehicle systems, isotope separation systems, airframe and engine components (GE-90 fan blades), and structures used in weapon systems.

Prepreg is the term used to describe cloth, mat, and unidirectional fiber bundles that have been impregnated with polymer resin to the point that it is ready for consolidation into a finished component or structure. This data sheet describes any such prepreg that contains any of the fibers with properties above the limits listed in Data Sheet 14.2-13 *or* any prepreg that contains a resin with a glass transition temperature of 145 °C or above, as illustrated in the Figure 14.2-1.

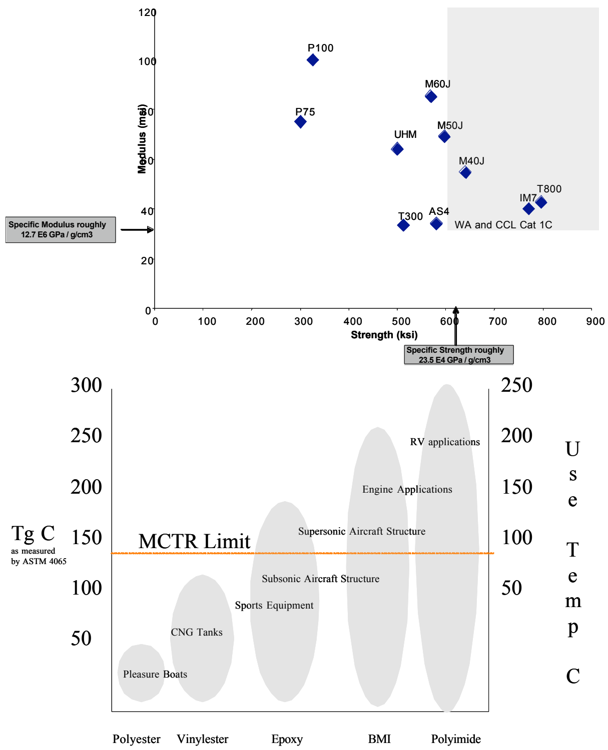

Figure 14.2-1. Resin-Impregnated Fiber Prepregs Based on Fibrous or Filamentary Reinforcements

MCTL DATA SHEET 14.2-16. FINISHED POLYMER MATRIX COMPOSITE PARTS OR LAMINATES

Critical Technology Parameter(s)	Finished polymer matrix composite parts that utilize either the fibers discussed in Data Sheet 14.2-13 *or* the resins described in 14.2-14. Processing know-how for the fabrication of finished composite parts.
Critical Materials	Materials defined on Data Sheets 14.2-13 to 14.2-15.
Unique Test, Production, Inspection Equipment	All equipment associated with the production of high-performance organic matrix composite components and structures, such as autoclaves, six-axis winding or fiber-placement machines.
Unique Software	Software that allows the precise control of autoclaves and automated lay-down equipment.
Major Commercial Applications	High-performance sporting goods, commercial aircraft and engine parts, and racecar components. Also commercial space launch vehicles.
Affordability Issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1, MCTR Cat 11, Item 6.

BACKGROUND

Data Sheets 14.2-13, 14.2-14, and 14.2-15 have addressed carbon fibers, polymer resins, and prepregs made thereof that are of particular interest for fabricating high-performance composite structures. This data sheet addresses finished composite parts made from one or more of these materials that are designed for use or potential use in defense systems and processing knowledge that could be used to fabricate finished composite parts.

MCTL DATA SHEET 14.2-17. DEVELOPMENT OR PRODUCTION OF PYROLYTICALLY DERIVED MATERIALS

Critical Technology Parameter(s)	Process details (temperature, pressure, gas flow rates) for producing near-theoretical density deposits of graphite, silicon, or other materials on mandrels or designated substrates.
Critical Materials	High-purity reactive precursor and carrier gases (hydrocarbon/methane, propane for graphite like carbon).
Unique Test, Production, Inspection Equipment	High-temperature chemical vapor deposition furnaces, nozzles, mandrels specific to desired parts, laser heat sources. Isostatic presses, fluidized bed furnaces.
Unique Software	Required for process control.
Major Commercial Applications	RF drives, plasma devices, ion guns, heat sinks, etching cathodes and grids, heart valves, rapid prototyping, nuclear fission energy research.
Affordability Issues	Products are performance critical and affordability is addressed through process reproducibility and yield.
Export Control References	WA Cat 1, CCL Cat 1, MTCR Cat 2, Item 6.

BACKGROUND

Pyrolytic graphite deposited on a mandrel or in a mold is the primary military product of a process, that is accomplished by decomposition of methane or propane in a high-temperature reaction chamber.

MCTL DATA SHEET 14.2-18. CARBON FIBER CARBON MATRIX COMPOSITES

Critical Technology Parameter(s)	Specific modulus exceeding 10.15×10^6 m and specific tensile strength exceeding 17.7×10^4 m; finished or semi-finished items specifically designed for purely civilian applications are not controlled. Finished density greater than 1.6 gm/cm^3 for heat shields and 1.9 gm/cm^3 for nose tips.
Critical Materials	High-modulus carbon fibers and graphite fibers including pitch, polyacrylonitrile, and high-thermal conductivity fibers. Pitch and resin matrix systems. Resins with char yields greater than 25% carbon have been suggested as another discriminator.
Unique Test, Production, Inspection Equipment	High-pressure densification (cold isostatic pressing, hot isostatic pressing) machines capable of weaving fiber architectures in two, three, or more dimensions, automated fabrication and chemical vapor deposition processing equipment, computed tomography inspection capability, impregnation equipment.
Unique Software	Process controls (i.e., weaving, densification time, temperature, pressure) and know-how.
Major Commercial Applications	Commercial spacecraft, reciprocating engine hot structures, and aircraft brakes.
Affordability issues	None identified.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Carbon fiber reinforced carbon composites provide a lightweight, very high-temperature structural material for military and some civilian applications.

MCTL DATA SHEET 14.2-19. CERAMIC FIBER REINFORCED CERAMIC MATRIX COMPOSITES

Critical Technology Parameter(s)	(1) *SiC-fiber-reinforced ceramic matrix composites*: Tensile strength at room temperature greater than 300 MPa (43 ksi) and creep strength greater than 140 MPa (20.3 ksi) at 1,200 °C for 100 hours. (2) *C-fiber-reinforced ceramic matrix composites*: Tensile strength at room temperature greater than 375 MPa (54 ksi). (3) *Oxide-fiber-reinforced ceramic matrix composites*: Tensile strength at room temperature greater than 200 MPa (29 ksi) and creep strength greater than 140 MPa (20 ksi) at 1,100 °C for 100 hours.
Critical Materials	(1) SiC-fiber-reinforced polymer derived C, SiC, SiCO and SiNC; melt infiltrated SiC; chemical vapor infiltrated SiC. (2) C-fiber-reinforced polymer derived SiC, SiCO and SiNC; melt infiltrated SiC; chemical vapor infiltrated SiC. (3) Oxide-fiber-reinforced sol-gel and slurry-derived alumina and aluminosilicates; polymer derived SiCO.
Unique Test, Production, Inspection Equipment	SiC fiber automated chemical vapor desposition processing equipment. Weaving equipment for special preforms.
Unique Software	Process-control software.
Major Commercial Applications	Power generation components under field trials; chemically resistant structures.
Affordability Issues	Still very costly.
Export Control References	WA Cat 1, CCL Cat 1.

BACKGROUND

Ceramic matrix composites are a class of materials that have high-strength and high-stiffness at elevated temperatures. They can have good toughness as well and are suited for high-temperature applications.

MCTL DATA SHEET 14.2-20. ANTI-ARMOR (TUNGSTEN KINETIC-ENERGY PENETRATORS)

Critical Technology Parameter(s)	Elongation greater than 3%, yield strength greater than 1,250 MPa, ultimate tensile strength greater than 1,270 MPa, density greater than 17.5 g/cm^3.
Critical Materials	Cobalt (binder).
Unique Test, Production, Inspection Equipment	Manufacturing, inspection, and test equipment for projectile components and subcomponents.
Unique Software	None identified.
Major Commercial Applications	Sporting goods (golf).
Affordability Issues	This technology avoids the environmental costs associated with depleted uranium penetrators.
Export Control References	Penetrators controlled in WA ML 3[1] and USML III, XXI.

BACKGROUND

Anti-armor includes kinetic energy penetrators of high-density materials, such as tungsten.

1 Includes associated controls for software and technology as specified in WA ML 18 and 22.

MCTL DATA SHEET 14.2-21. ANTI-ARMOR (DEPLETED URANIUM KINETIC-ENERGY PENETRATORS)

Critical Technology Parameter(s)	In bar stock and as fabricated penetrator density greater than 18 gm/cm^3, yield strength greater than 850 MPa, ultimate tensile strength greater than 1,200 MPa, elongation greater than 20%.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability Issues	Cleanup costs increase overall expense.
Export Control References	WA ML 3,[2] USML III, XXI.

BACKGROUND

Anti-armor includes kinetic energy penetrators of high-density materials, such as depleted uranium.

[2] Includes associated controls for software and technology as specified in WA ML 18 and 22.

MCTL DATA SHEET 14.2-22. ANTI-ARMOR (COPPER OR TANTALUM SHAPED–CHARGE LINERS)

Critical Technology Parameter(s)	Density greater than 95% of theoretical.
Critical Materials	Not applicable.
Unique Test, Production, Inspection Equipment	Shear/spin forming equipment capable of forming these materials to required tolerances.
Unique Software	Programs to control rolling or forging of these materials.
Major Commercial Applications	None identified.
Affordability Issues	Tantalum much more expensive than copper.
Export Control References	WA ML 3,[3] USML III.

BACKGROUND

Shaped-charge liners of ductile metals are important anti-armor materials.

3 Includes associated controls for software and technology as specified in WA ML 18 and 22.

SECTION 14.3—MATERIALS FOR SURVIVABILITY

Highlights

- This section covers only ballistic protection and armor materials.
- Fully dense (close to zero porosity), very hard ceramics such as silicon carbide (SiC), aluminum oxide (Al_2O_3), titanium diboride (TiB_2), and boron carbide (B_4C) offer excellent ballistic protection. Many countries produce ceramic armor.
- Laminate composites (arrays of metal or ceramic plates, woven cloth, low-density foams) can be designed to resist fragmentation, impede transmission of shock waves, or change orientation of a projectile before penetration.

OVERVIEW

Although this section is titled “Materials for Survivability,” it addresses only those technologies concerned with protection from ballistic threats. Other elements of survivability, such as laser protection, chemical/biological weapon protection, concealment, and confusion, are addressed in other sections of the MCTL. For example, laser protection is dealt with in Section 11, Lasers, Optics and Imaging Technology. This includes eye and sensor protection, passive optical limiting, and wavelength filtering. Anti-armor materials are likewise discussed in Section 14.2, Structural Materials (High-strength and High-Temperature, Anti-armor).

The ballistic protection and armor materials covered in this section include ceramics and related composites and hybrid composite engineered systems. Of special interest are ceramics that are near theoretical density (greater than 98 percent, less than 2-percent porosity; e.g., titanium diboride, boron carbide, and silicon carbide); composite materials: arrays of metal plates and ceramics; arrays of woven cloth, ceramics and metals; ceramics or single crystal whiskers in a bonded matrix; and layers of metals. Applications include armor protection of platforms and vehicles and tactical shelters.

BACKGROUND

Advanced ballistic protection and armor materials include high-strength, fracture-resistant alloys and near-theoretical-density hard ceramics and laminate multimaterial composites and appliqué configurations. Control of processing and resulting microstructure of armor materials is crucial for achieving the properties and resulting performance needed by the military. High-strain-rate testing and computer codes are employed extensively in this work. Potential payoffs in the armor materials area include affordable armor materials for weight and volume reduction in combat systems to enhance transportability, survivability, lethality, and agility. Materials and armor packages are designed for specific threats.

LIST OF MCTL TECHNOLOGY DATA SHEETS
14.3. MATERIALS FOR SURVIVABILITY

MCTL DATA SHEET 14.3-1. SILICON CARBIDE

Critical Technology Parameter(s)	Density equal to or greater than 98% theoretical.
Critical Materials	Silicon carbide powder, sintering additives, oxidation inhibitors.
Unique Test, Production, Inspection Equipment	Vacuum or inert atmosphere hot-pressing equipment and carbon-based tooling.
Unique Software	Furnace control software.
Major Commercial Applications	Paper-processing components, abrasive blast nozzles, chemical and metal processing support, metal and ceramic surface finishing, and semiconductor processing components.
Affordability Issues	Powder costs vary depending upon the quantity, average size, and purity of the starting powders, and as of 2003 fell in the range of $2–$200+ per pound (armor-grade hot-pressing powder was around $5–$6/lb). The finished product cost for armor tiles typically varies between 5 and 20 times the cost of the starting powder depending upon quantity, tile size, the method used for densification (e.g., pressureless-sintering versus hot-pressing), and the amount and quality of final machining.
Export Control References	None.

BACKGROUND

Silicon carbide has been evaluated for use in armor applications since the late 1960s. The first silicon carbide to be used in military applications was the reaction-bonded variant. Reaction-bonded silicon carbides typically consist of approximately 75 vol.-percent silicon carbide, 15–20 vol.-percent silicon, and 5–10 vol.-percent porosity. Their performance was slightly better than the sintered aluminum oxides of the time. Unfortunately, processing difficulties resulted in an inconsistent product especially for thick plates (greater than 20 mm). Processing improvements in the 1970s led to the development of sintered silicon carbides, which were essentially monolithic with densities in excess of 98 percent of theoretical. Their performance was substantially better than the ever-improving sintered-grade aluminum oxides; however, their cost severely limited their application and use. During the 1980s, the development of hot-pressing technology, coupled with the fall in industrial-grade silicon carbide powder prices, led to the development of hot-pressed variants of silicon carbide. These offered superior performance at competitive cost compared with the sintered silicon carbide. Continual drops in powder prices and improvements in powder quality and powder processing during the 1990s has made hot-pressed variants of silicon carbide the current state of the art in performance and cost against a wide variety of threats (up to medium caliber) for vehicle applications. In addition, improvements in the reaction-bonded and sintered silicon carbide processing technologies have led to the application of these variants in personnel body armors for protection against National Institute of Justice level III threats.

MCTL DATA SHEET 14.3-2. TITANIUM DIBORIDE

Critical Technology Parameter(s)	Density equal to or greater than 98% theoretical.
Critical Materials	Titanium diboride powder.
Unique Test, Production, Inspection Equipment	Vacuum or inert atmosphere hot-pressing equipment and carbon-based tooling.
Unique Software	None identified.
Major Commercial Applications	Sputter targets for deposition of thin films and coatings for optical, dielectric (cathode coatings for aluminum processing), and wear applications.
Affordability Issues	Powder costs vary depending upon the quantity, average size, and purity of the starting powders, and as of 2003 fell in the range of $50–$100+ per pound. The finished product cost for armor tiles was typically in excess of $200/lb depending upon the cost of the starting powder, quantity, tile size, the method used for densification (e.g., pressureless-sintering versus hot pressing), and the amount and quality of final matching.
Export Control References	None.

BACKGROUND

Titanium diboride was examined as a potential armor material for vehicle protection applications during the late 1980s and early 1990s. Compared with the other ceramics of the time, it was found to be the best performer against long-rod kinetic energy penetrators. However, processing improvements in the early generation hot-pressed silicon carbides variants led to the development of armor-grade silicon carbides with performance that nearly equaled that of titanium diboride. Subsequent silicon carbide powder price decreases eventually solidified silicon carbide’s position as a viable commercial product for armor applications. However, titanium diboride is still considered to be the best performing ceramic against heavy-caliber threats.

MCTL DATA SHEET 14.3-3. BORON CARBIDE

Critical Technology Parameter(s)	Density equal to or greater than 98% theoretical.
Critical Materials	Boron carbide powder, sintering additives.
Unique Test, Production, Inspection Equipment	Vacuum or inert atmosphere hot-pressing equipment and carbon-based tooling.
Unique Software	None identified.
Major Commercial Applications	Paper-processing components, abrasive blast nozzles, chemical and metal processing support, metal and ceramic surface finishing, and semiconductor processing components.
Affordability Issues	Powder costs vary depending upon the quantity, average size, and purity of the starting powders, and as of 2003 fell in the range of $15–$225 per pound (armor-grade hot-pressing powder was around $15–$20/lb). The finished product cost for armor tiles typically varies between 5 and 15 times the cost of the starting powder depending upon quantity, tile size, the method used for densification (e.g., pressureless-sintering versus hot-pressing), and the amount and quality of final machining.
Export Control References	None.

BACKGROUND

Boron carbide has been evaluated for use in armor applications since the late 1960s. Against threats up to 12.7-mm armor-piercing (steel core), boron carbide is the ceramic of choice for developing the lightest weight survivability technologies for infantry soldiers and air crews.

MCTL DATA SHEET 14.3-4. COMPOSITE MATERIALS SPECIALLY DESIGNED FOR KINETIC ENERGY ABSORPTION TO RESIST FRAGMENTATION OR TO IMPEDE SHOCK–WAVE TRANSMISSION

Critical Technology Parameter(s)	Two– and three–dimensional arrays of integrated/structured materials systems (as in ribs, I-beam stiffeners) composed of, but not limited to, metallic, ceramic, polymeric, and hybrid composite solids, foams, and woven cloths specially designed to absorb kinetic (and blast) energy, to resist fragmentation, to impede transmission of shock waves, and to prevent perforation. Thus, each configuration is application-design specific.
Critical Materials	Hybrid Composite Engineered System.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	CAD/CAM design codes.
Major Commercial Applications	Automotive.
Affordability Issues	None identified.
Export Control References	WA ML 13,[4] USML X.

BACKGROUND

Design and selection of suitable materials systems for kinetic energy protection are often limited by application-driven constraints. For our purposes, kinetic energy includes solid mass at high velocity and air mass at high pressure. Compromises are often made for weight, volume, and cost budget. Conventional design strategy to mitigate the effects of kinetic energy is to integrate micro and macro materials system functionally sensitive to the rate of energetic loading. Material systems of metals (steel, titanium, aluminum, magnesium), ceramics (structural oxides and carbides, concrete), polymer (polycarbonate, rubber) and composites (glass fiber and carbon-fiber-reinforced polymer) have been used or are being considered in two- and three-dimensional design for this purpose. For example, military designers are beginning to adopt more lightweight composite armor across the board for light, medium, and heavy trucks like those being used in Iraq.[*] Engineering combinations of metallic beam structure with integrated energy absorbing and mitigating materials bonded to structural composites have successfully been demonstrated for kinetic energy protection.

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[4] Includes associated controls for software and technology as specified in WA ML 18 and 22.

[*] *High Performance Composites*, January 2005, p. 26.

MCTL DATA SHEET 14.3-5. TRANSPARENT ARMOR

Critical Technology Parameter(s)	Density equal to 100% theoretical. Transparent in the wavelengths of interest, ranging in the UV, visible, and infrared frequencies.
Critical Materials	Aluminum oxynitride (AION), spinel, sapphire, polycarbonate, polyurethane.
Unique Test, Production, Inspection Equipment	Vacuum or inert atmosphere hot-pressing equipment and carbon-based tooling.
Unique Software	None identified.
Major Commercial Applications	Armor for law-enforcement personnel (e.g., riot gear, face shield, security glass).
Affordability Issues	The cost is generally high.
Export Control References	WA ML 13,[5] USML X.

BACKGROUND

Current glass/polycarbonate technologies for transparent armor cannot meet all of today's requirements for transparent protection. Transparent single crystal and polycrystalline ceramics and advanced polymers greatly improve the performance of a system.

[5] Includes associated controls for software and technology as specified in WA ML 18 and 22.